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UNSTABLE-RESONATOR AND OUTPUT-COUPLING DESIGN STUDY FOR DIFFRAC--ETC(U)
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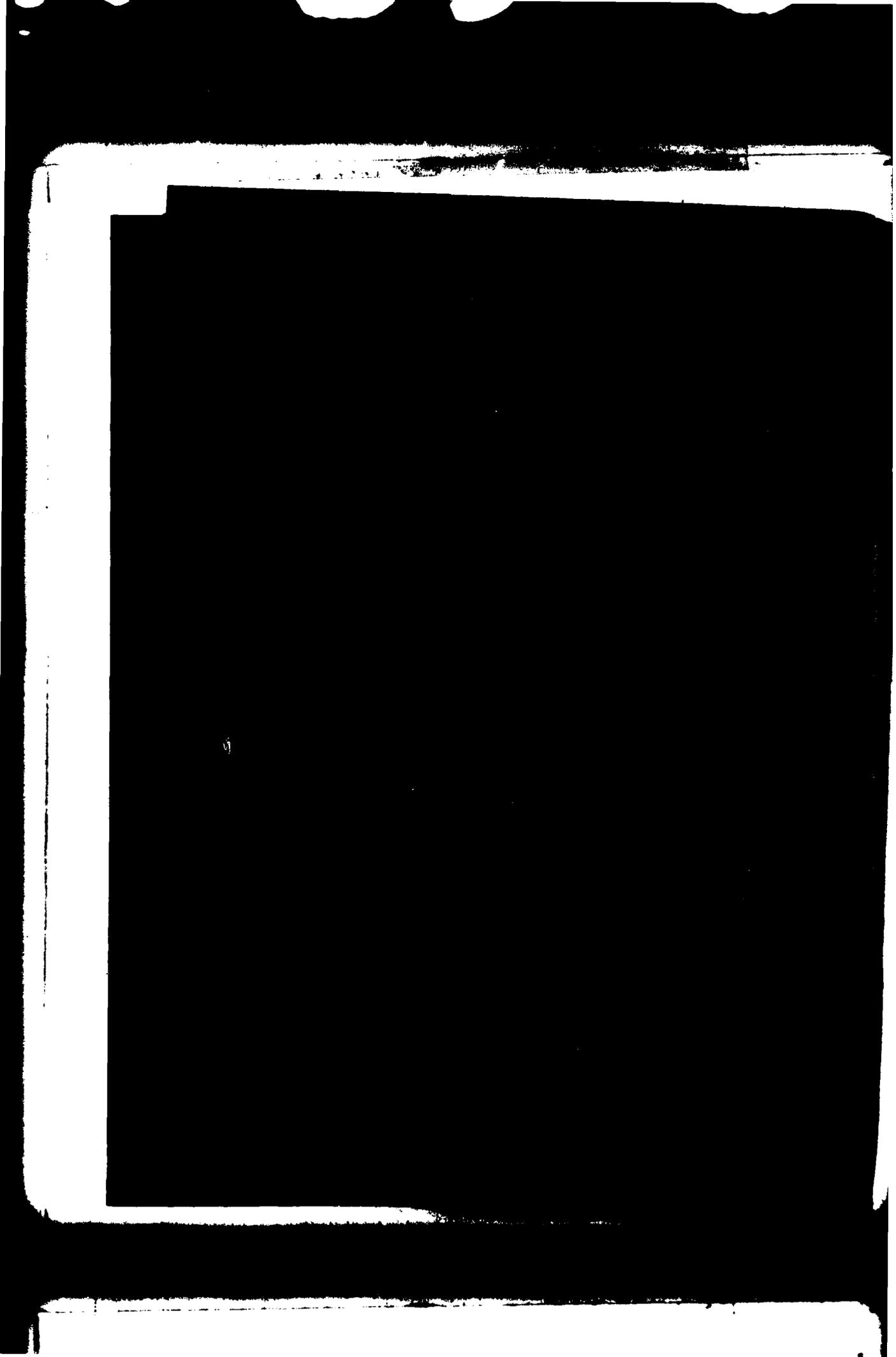
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Configurations of unstable resonators that could be used for
diffraction radiation generators (DRG's) are presented. The
output coupling of a negative branch unstable resonator exhibits
an extreme sensitivity to mirror radius and appears to be
unsuited to DRG use. The positive branch resonator does not
exhibit this sensitivity to mirror radius, and the mirror radii
that are needed to give diffraction output couplings of a few
percent are practical.

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1. INTRODUCTION

A number of papers have been published on free-electron lasers of the Smith-Purcell type. These lasers are known as diffraction radiation generators[1] (DRG's), oratrons,[2] and ledatrons.[3] They consist basically of an electron-beam generator and collector and a metallic reflection diffraction grating embedded in a mirror, which with another mirror forms the optical resonator. The optical resonator reflects radiation emitted by electrons in the ribbon-like electron beam as they pass over the diffraction grating, causes the electrons to bunch, and causes the radiation to have cavity properties.

A portion of the energy stored in the optical resonator is generally coupled out of the resonator to waveguide lines by small apertures in the mirror that does not have the diffraction grating embedded in it.[3-5] This method of coupling-out power is not a problem when the resonator operates at wavelengths of a few millimeters. At shorter wavelengths, however, it becomes increasingly difficult to fabricate output coupling apertures that are small and that do not introduce unacceptably high losses to the system. In addition, there are severe technical difficulties in devising prescribed values for the coefficient of coupling between the resonator cavity and any external load. In a DRG, the gain appears to be low,[6] and the choice of the output coupling has a large effect on operating characteristics, output power, and efficiency.[7]

These problems of achieving the correct (optimum) output coupling are alleviated if quasi-optical coupling techniques are used.[8] Although quasi-optical output coupling techniques do exist, they are said to be too complicated for practical use and are not widely used.[7]

[1] V. P. Shestopalov, Diffraction Electronics, Khar'kov (1976); translation by U.S. Joint Publications Research Service (April 1978); U.S. Army Foreign Science and Technology Center Document 923-77.

[2] F. S. Rusin and G. D. Bogomolov, Proc. IEEE, 57 (April 1978), 720.

[3] K. Mizuno, IEEE Trans. Electron Devices, 20 (August 1973), 749-752.

[4] F. S. Rusin and G. D. Bogomolov, JETP Letters, 4 (1968), 160.

[5] V. P. Shestopalov, I. M. Balakletsky, and O. A. Tret'yakov, Electrotech., 12 (1972), 50.

[6] I. M. Balakliskii, I. D. Revin, B. K. Skrynnik, A. S. Sysoev, O. A. Tret'yakov, and V. P. Shestopalov, Izv. Vyssh. Uchebn. Zaved. Radiofiz., 16 (February 1973), 235-243.

[7] V. G. Kurin, B. K. Skrynnik, and V. P. Shestopalov, Izv. Vyssh. Uchebn. Zaved. Radiofiz., 19 (January 1976), 128-134.

[8] G. D. Bogomolov and F. S. Rusin, Radio Eng. Electron. Phys., 15 (1970), 727-728.

A resonator output coupling technique is considered here that appears to offer solutions to some of the problems mentioned above for use with DRG's. The technique is not unduly complicated and is likely to improve the narrowness of spectral output over normal stable resonators incorporating hole or slit coupling. The design is the so-called unstable resonator,[9] in which the output coupling is achieved by diffraction from around the edge of one of the resonator mirrors.[10] Unstable resonator design techniques are widely used in high power gas lasers to extract as much energy as possible from large volumes that can exhibit large optical gain, yet that often have index inhomogeneities that adversely affect the (stable) resonator beam quality.[11,12] It is also a design technique used to considerable advantage with low energy solid-state lasers such as ruby, neodymium (Nd):glass, Nd:yttrium aluminum garnet (YAG), and dye lasers that are characterized by moderate to high gain.[12] The demonstrated advantages that follow from the use of unstable resonators are variable output coupling, large mode volume, excellent transverse-mode control, single-mode oscillation, efficient energy extraction, far-field brightness, and automatically collimated (or even focussed) output beams.[12,13] There do not appear to be any serious flaws lurking in the unstable resonator design concept.[12]

1.1 General Properties of Unstable Resonators

An optical resonator is generally composed of two flat or curved mirrors facing each other. Figure 1 illustrates a typical stable resonator, a generalized symmetric unstable resonator, and a specific (unsymmetric) unstable resonator with the output diffraction coupled entirely from one end.[13] Single ended output coupling from only one end of the resonator is obtained by making one of the unstable resonator mirrors larger than the other.

The properties of a general optical resonator can be given in terms of the normalized curvature, or g parameters,[9,14]

$$g_j = 1 - \left(L/R_j\right), \quad j = 1, 2,$$ (1)

and the Fresnel numbers,

$$N_j = a_j^2/\lambda L ,$$ (2)

[9]A. E. Siegman, Proc. IEEE, 53 (March 1965), 277–287.

[10]C. S. Willett, Patent Disclosure 78-32 (June 1978).

[11]A. E. Siegman, Laser Focus (May 1971), 42–47.

[12]A. E. Siegman, Appl. Opt., 13 (February 1974), 353–367.

[13]A. E. Siegman and R. W. Arrathoon, IEEE J. Quantum Electron., QE-3 (1967), 156.

[14]W. F. Krupke and W. R. Sooy, IEEE J. Quantum Electron., QE-5 (December 1969), 575–586.

where L is the distance between the two mirrors, R_j is the radius of curvature of the jth mirror (defined as positive if the center of curvature lies toward the interior of the resonator), and $2a_j$ is the diameter of the jth mirror. With these definitions, the parameter space of two mirrors, g_1 and g_2, can be divided into stable and unstable regions as shown in figure 2, where the stable (shaded) region is defined by the analytic condition

$$0 \leq g_1 g_2 \leq 1 .$$ (3)
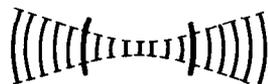
STABLE

SYMMETRIC UNSTABLE

UNSYMMETRIC UNSTABLE

Figure 1. Examples of typical stable and unstable resonators *(from A. E. Siegman and R. W. Arrathoon, IEEE J. Quantum Electron., QE-3 (1967), 156).*
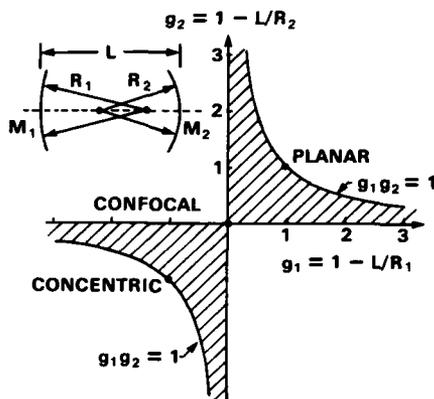
Figure 2. General optical resonator (insert) and mode chart that summarizes mode stability properties; unstable resonators lie outside shaded regions *(from A. E. Siegman, Proc. IEEE, 53 (March 1965), 278).*

There are two general types of unstable resonators, negative branch and positive branch. Negative branch unstable resonators have products of their g parameters

$$g_1 g_2 < 0 .$$ (4)

Positive branch unstable resonators have

$$g_1 g_2 > 1 .$$ (5)

Figure 3 illustrates typical unstable resonator mode patterns from various portions of the mode chart shown in figure 2.

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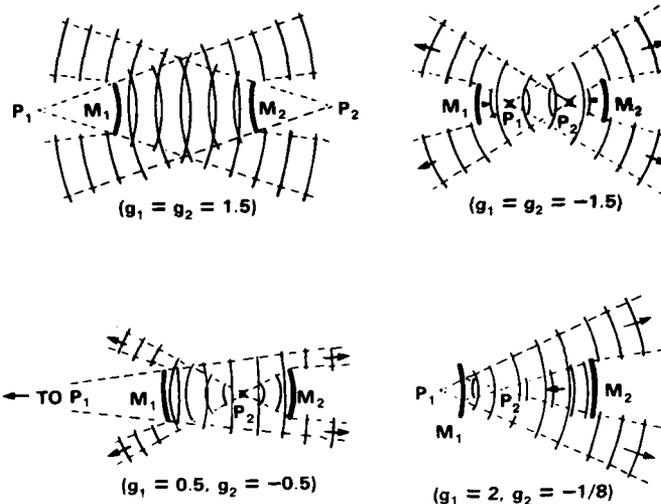
Figure 3. Typical unstable mode
patterns illustrating mode behavior
in different unstable regions of
mode chart *(from A. E. Siegman,
Proc. IEEE, 53 (March 1965), 280).*

The most useful form of unstable resonator geometry for conventional lasers (not DRG's) is the so-called confocal or telescopic unstable resonator in an asymmetrical form. The two general types of confocal unstable resonators are illustrated in figure 4. Both give collimated beam outputs. The confocality condition requires

$$\left(R_1/L\right) + \left(R_2/L\right) = 2 \ ,$$

or

$$g_1 = g_2/\left(2g_2 - 1\right) \ . \tag{6}$$

The negative branch confocal configuration has significant practical advantages in the form of more easily obtainable shorter radius mirrors and considerably easier mirror alignment tolerances.[14] However, because the internal focal point in the negative branch configuration leads to difficulties with optical breakdown,[12] the positive branch resonator is used most often with high energy gas laser systems.

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[12]*A. E. Siegman, Appl. Opt., 13 (February 1974), 353-367.*

[14]*W. F. Krupke and W. R. Sooy, IEEE J. Quantum Electron., QE-5 (December 1969), 575-586.*

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In any final practical design of an unstable resonator for a DRG, it is envisioned that the output mirror, M_2, be deposited on a larger optical element through which the energy diffracted beyond the edge of M_2 can be transmitted. Further, by a suitable combination of radii of curvatures of the first and second surfaces of the output element, the output radiation can be suitably converged and coupled to outside circuitry. It is further proposed that the output optical element provide a vacuum seal between the volume of the DRG in which the electron beam interacts with the diffraction grating and any external circuitry or load (fig. 5).
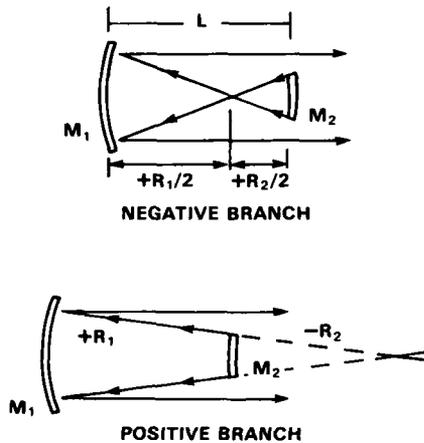
Figure 4. Negative and positive branch confocal unstable resonators.
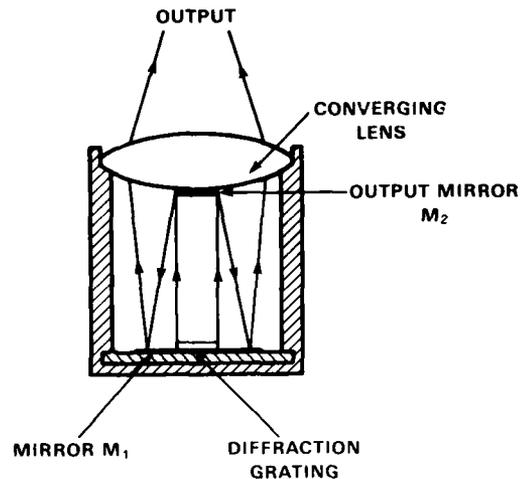
Figure 5. Basic configuration of unstable resonator for closed-off diffraction radiation generator.

1.2 Diffraction Losses

The waves in an unstable resonator not only fill the mirrors of the resonator, but spread to become larger than the mirrors by a magnification factor that depends only on the resonator g parameters. The radiation that goes past the outer edges of the output mirror, which would normally be a loss, constitutes the output coupling from the resonator. This coupling depends only on the linear magnification, M, and can be calculated from basic geometric principles. It is independent of the mirror sizes, wavelength, and Fresnel number. The linear magnification is equal to the ratio of the mirror diameters. It is possible then to have relatively large diameter modes even in relatively short unstable resonators. Having them would be difficult with stable resonator configurations, which are usually long and narrow.

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A general expression for the asymmetric linear round-trip magnification of an unstable resonator is given by[11]

$$M = 2g_1 g_2 + 2 \left[g_1 g_2 \left(g_1 g_2 - 1 \right) \right]^{1/2} - 1 . \tag{7}$$

The average fractional power output coupling per one-way pass, δ, through the system is given in the three-dimensional (spherical mirror) case in terms of M by[15]

$$\delta_{disc} = 1 - \left(1/M^2 \right) \tag{8}$$

and in the two-demensional (strip or cylindrical mirror) case by

$$\delta_{strip} = 1 - \left(1/M \right) . \tag{9}$$

The output power coupling can be designed to fall anywhere from a few percent to 95 percent per pass as required for a particular laser system. The output coupling for high-gain gas laser systems usually exceeds 30 percent. With DRG's, the optical gains appear to be only a few percent; therefore, the output couplings are expected also to be only a few percent.

The average fractional power output coupling per one-way pass through the system is related to the average fractional power transmission (reflection) per pass, Γ, by

$$\delta = 1 - \Gamma . \tag{10}$$

Siegman has shown[9] that

$$\Gamma^2_{strip} = \pm \frac{1 - \left(1 - \dfrac{1}{g_1 g_2} \right)^{1/2}}{1 + \left(1 - \dfrac{1}{g_1 g_2} \right)^{1/2}} , \tag{11}$$

[9] A. E. Siegman, Proc. IEEE, *53* (March 1965), 277-287.

[11] A. E. Siegman, Laser Focus (May 1971), 42-47.

[15] D. B. Rensch and A. N. Chester, Appl Opt, *12* (1973), 997-1010.

where Γ_{strip} is the average power transmission per pass for strip (cylindrical) mirrors, the upper (+) sign is valid for g values in the first and third quadrants of the mode chart, and the lower (−) sign is valid for the second and fourth quadrants.

For circular (disc) mirrors,

$$\Gamma_{disc} = \Gamma_{strip}^2 \quad . \tag{12}$$

Since the g parameters do not involve the sizes or the shapes of the mirrors, Γ_{strip} and Γ_{disc} are independent of these parameters and depend only on the mirror separation, L, and the radii of curvature, R_1 and R_2.

1.3 Confocal Resonators

Figure 4 shows the geometry of negative branch and positive branch confocal resonators. For the negative branch confocal unstable resonator,

$$R_1 = 2ML/(M + 1) \; ,$$

$$R_2 = 2L/(M + 1) \quad .$$

For the positive branch confocal unstable resonator,

$$R_1 = 2ML/(M - 1) \; ,$$

$$R_2 = -2L/(M - 1) \quad .$$

Each radius of curvature is directly proportional to the separation of the mirrors for both negative and positive branch confocal unstable resonators and is independent of the mirror sizes.

2. OPTIMUM OUTPUT COUPLING FOR DIFFRACTION RADIATION GENERATOR

To achieve maximum output power from a DRG, the output coupling must be matched to the gain of the DRG at its operating point.

Resonator losses in DRG's are primarily (1) ohmic losses at the mirrors, (2) diffraction and reflection losses, (3) scattering losses at the mirrors, or (4) output coupling losses.[16]

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[16]D. E. Wortman and R. P. Leavitt, *Research Study on Near Millimeter Wave Oratrons, Harry Diamond Laboratories HDL-SR-80-4 (July 1980).*

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All indications[1] are that losses in DRG's are dominated by ohmic losses and that these are primarily due to the presence of the reflection grating.

Although measurements of the gain of DRG's from which one might be able to calculate optimum output couplings are not available from the literature, actual transmission coefficients of DRG's operating with quasi-optical output coupling have been published.[6] These transmission coefficients are of the order of a few percent and, therefore, are the order of the output couplings that can be tolerated in a DRG. A few percent is assumed in this report to be typical of the output coupling of a DRG (operating at a wavelength of 4 mm).

3. UNSTABLE RESONATOR DESIGN FOR DIFFRACTION RADIATION GENERATOR

Values have been calculated for mirror curvatures R_1 and R_2 for negative and positive branch unstable resonators (using disc or spherical mirrors) for output couplings that range from 3 to a few tens of percent. Figure 6 gives values of output coupling for values of R_1 for mirror separations of 1, 2, 4, and 6 cm. A mirror separation of 2 cm is typical for a stable resonator DRG and is probably appropriate for any unstable resonator DRG operating at wavelengths of a few millimeters. Figure 7 shows the variation of output coupling with mirror radius R_1 for an unstable confocal resonator mirror separation of 1 cm. Since R_1 is directly proportional to the mirror separation, R_1 can be found from figure 7 for any value of mirror separation if the value of R_1 given in the figure is multiplied by L in centimeters. (This is why a 1-cm mirror separation is used in calculating data given in the figure, rather than a 2-cm separation, which is probably appropriate for a DRG operating in the near-millimeter region.)

As seen in figure 6, the variation of output coupling of the negative branch confocal unstable resonator is a very strong function of the mirror radius R_1 (and R_2). The output coupling changes (for a mirror separation of 2 cm) from 3 to 10 percent for a change in mirror radius of curvature (R_1) of 0.03 cm. At the lowest output couplings shown in figure 6, a mirror radius change of 0.01 cm can change output coupling from 3 to 5 percent. In view of this extreme sensitivity of the output coupling to mirror radius, which would be hard to manufacture to the required accuracy for a particular output coupling, the negative branch confocal resonator appears unsuited for use with DRG's.

[1]*V. P. Shestopalov, Diffraction Electronics, Khar'kov (1976); translation by U.S. Joint Publications Research Service (April 1978); U.S. Army Foreign Science and Technology Center Document 923-77.*

[6]*I. M. Balakliskii, I. D. Revin, B. K. Skrynnik, A. S. Sysoev, O. A. Tret'yakov, and V. P. Shestopalov, Izv. Vyssh. Uchebn. Zaved. Radiofiz., 16 (February 1973), 235-243.*

60 — R₁ =   1.23 cm   2.45 cm   4.9 cm

7.02 cm

30 —   1.089   2.18   4.36   6.53

20 —   1.056   2.11   4.22   6.33

10 —   1.026   2.05   4.11   6.16

                   2.04   4.06   6.09

5 —   1.013   2.03   4.05   6.08

3 —   1.008   2.02   4.03   6.05

L = 1 cm   L = 2 cm   L = 4 cm   L = 6 cm

OUTPUT COUPLING (%)

R₁   R₂   NOTE: R₁ + R₂ = 2L.

L

1 └─────────────────────────────────────
0   1   2   3   4   5   6   7
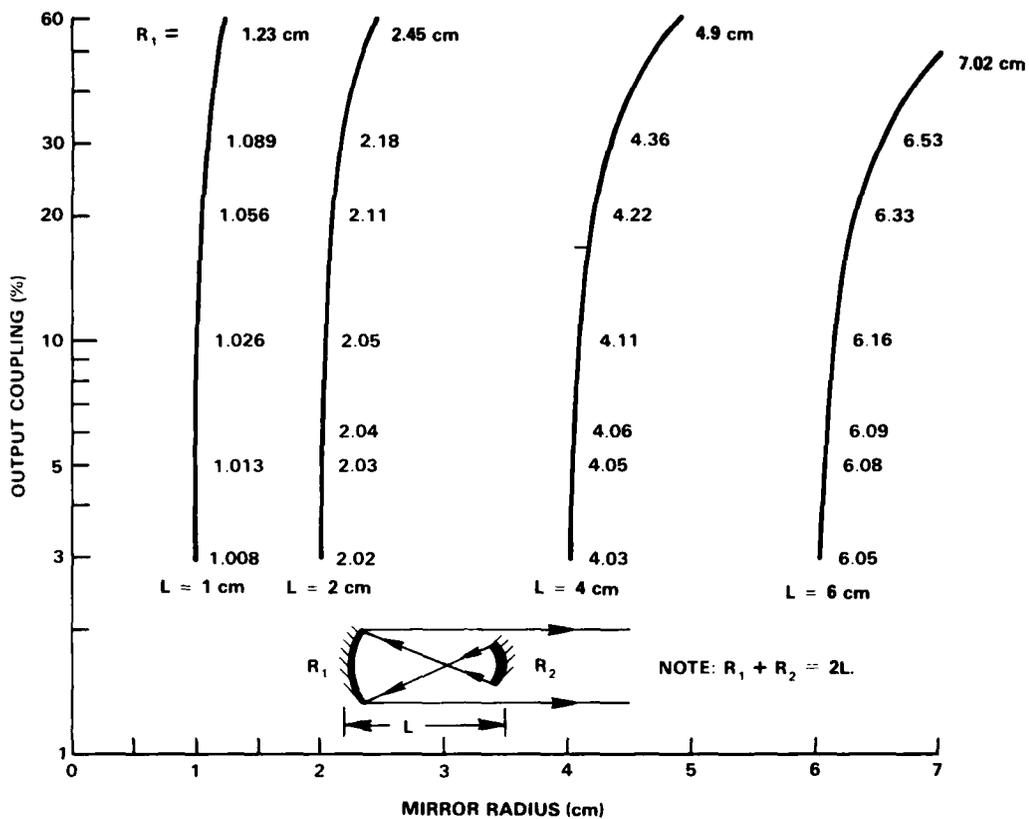
MIRROR RADIUS (cm)

Figure 6. Variation of output coupling of diffraction
radiation generator with mirror radius (R_1) of
negative branch confocal unstable resonator.

Unlike the behavior of the negative branch confocal reso-
nator, the variation of output coupling of a positive branch confocal
unstable resonator is not a sensitive function of the mirror radius.
This insensitivity is particularly so at the lowest output couplings.
For a mirror separation of 1 cm and an output coupling of 3 percent, a
mirror curvature of 132 cm is required. (Hence, for a mirror separation
of 2 cm, a mirror curvature of 264 cm is required.) For a 4-percent
output coupling and L = 2 cm, R_1 is approximately 198 cm. Mirrors of
this curvature with a specified tolerance for a particular output
coupling are no problem to manufacture.

The presence of one of the essential elements, the planar or strip
diffraction grating in a DRG, limits the construction of resonators. Up
to now, the most successful designs have used a single surface cylin-
drical mirror as a lower (non-output) mirror along whose generatrix the

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axis of the grating is situated (fig. 8). The upper mirror, through which there is some form of output coupling (usually hole or slit coupling), completes the cavity. To spread out the cavity mode along the length of the grating, the upper mirrors have incorporated compound or multiple-radii spherical surfaces.[1,17] In all DRG's, in the choice of (stable) resonators, the aim is to obtain two things: (1) a high-Q cavity with as extensive a cavity mode over the diffraction grating as possible and (2) a region of high electric field strength localized over the surface of the grating.
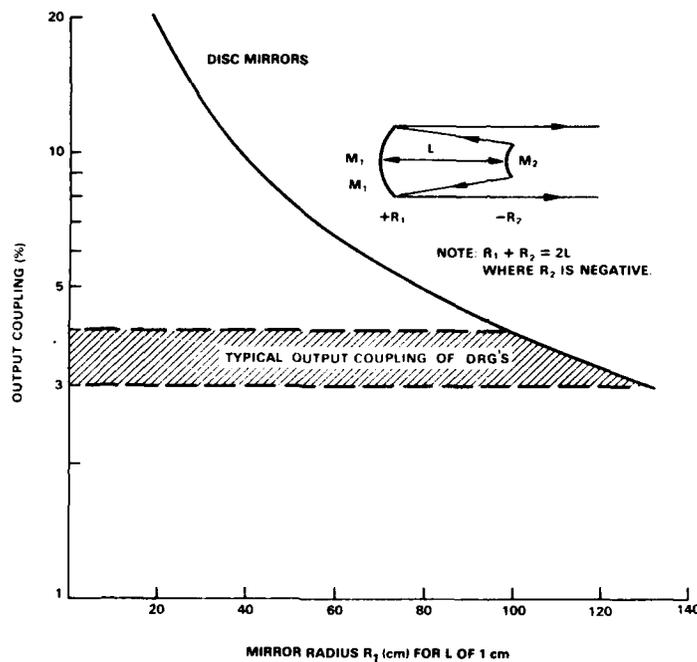

Figure 7. Variation of output coupling of diffraction radiation generator with mirror radius (R_1) of positive branch confocal unstable resonator.

Figure 8. Schematic diagram of diffraction radiation generator (from V. K. Korneenkov and V. P. Shestopalov, Radio Physics and Quantum Electron, 20 (1977), 88).
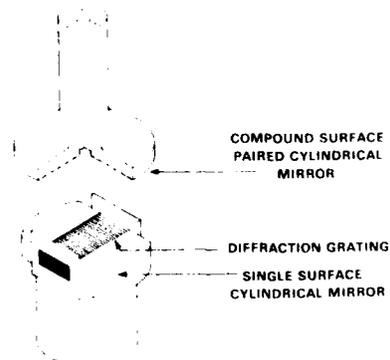

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[1] V. P. Shestopalov, Diffraction Electronics, Khar'kov (1976); translation by U.S. Joint Publications Research Service (April 1978); U.S. Army Foreign Science and Technology Center Document 923-77.

[17] V. K. Korneenkov and V. P. Shestopalov, Radiophys. Quantum Electron., 20 (1977), 87-90.

The requirement for the presence of a planar grating with as long an interaction region with the electron beam as possible similarly limits the design of an unstable resonator for a DRG. Possible basic positive branch unstable resonator designs for DRG's are shown in figure 9. To accommodate the strip diffraction grating, a simple cylindrical (or strip) mirror or planar mirror is used for the bottom mirror, and a cylindrical output mirror is used. With these designs, the output would occur as strips along the two longitudinal edges of the upper mirror, parallel to the diffraction grating.

Also, unstable and stable resonator mirror configurations can be combined, such as those shown in figure 10. The objective in these designs is to spread the cavity mode along the length of the grating while maintaining its lateral extent across the width of the grating. The resonators are unstable along the axes of the grating, but are stable across the grating width.

M, CYLINDRICAL MIRROR

M, PLANE MIRROR
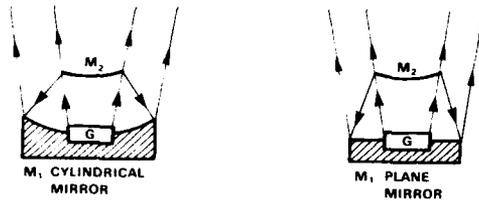
NOTE: G - DIFFRACTION GRATING.

Figure 9. Possible basic configurations of cylindrical mirrors of positive branch unstable resonators for diffraction radiation generator.

Figure 10. Combined unstable and stable resonator configurations for diffraction radiation generator.
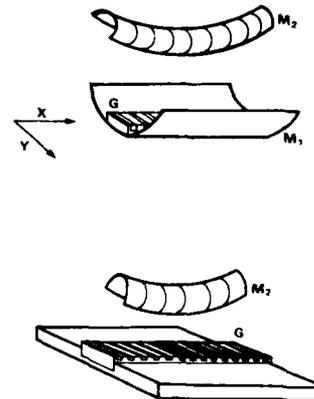
NOTES: IN X-DIRECTION, CAVITY IS UNSTABLE.
IN Y-DIRECTION, CAVITY IS STABLE.
G = DIFFRACTION GRATING.
M = MIRROR.

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Figures 11 and 12 present calculated values of the output coupling
of confocal and asymmetric negative branch and positive branch unstable
resonators as a function of the resonator mirror radius. The calcu-
lations are for a cylindircal mirror separation of 2 cm. The output of
the asymmetric unstable resonators is not collimated, as it is with the
confocal resonator geometry, and probably diverges strongly.

As might be anticipated, the variation of the output coupling of the
negative branch strip mirror unstable resonators is similar to that of
the negative branch disc mirror confocal unstable resonators (fig. 6).
At output couplings of a few percent, there_is an extensive sensitivity
of the output coupling to mirror radius. Since one is probably dealing
with output couplings of a few percent, the negative branch unstable
resonator would appear unsuited for use as a DRG resonator.
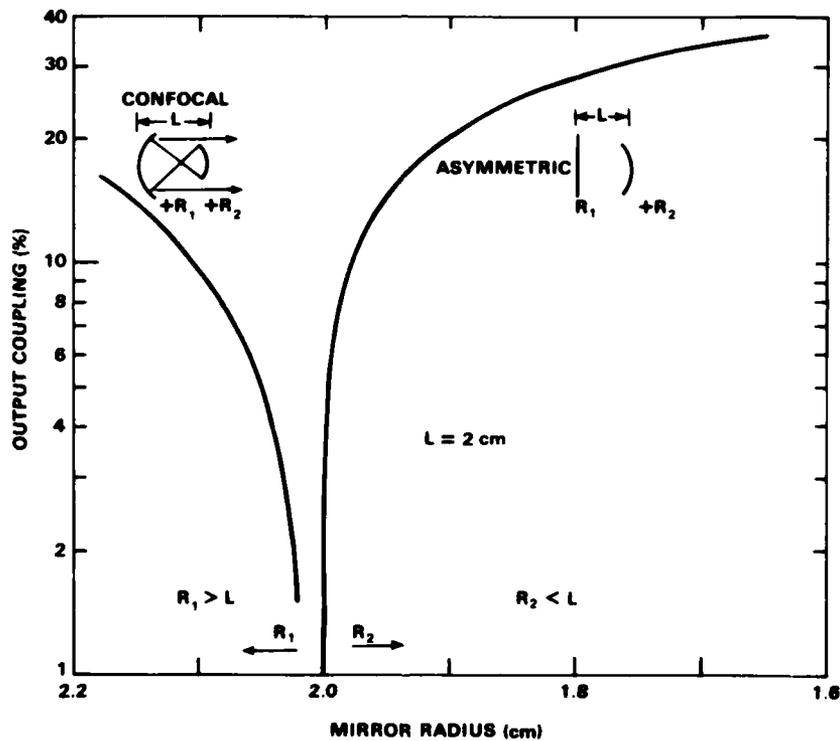
Figure 11. Variation of output coupling
of diffraction radiation generator with
cylindrical mirror radius of negative
branch asymmetric unstable resonators.

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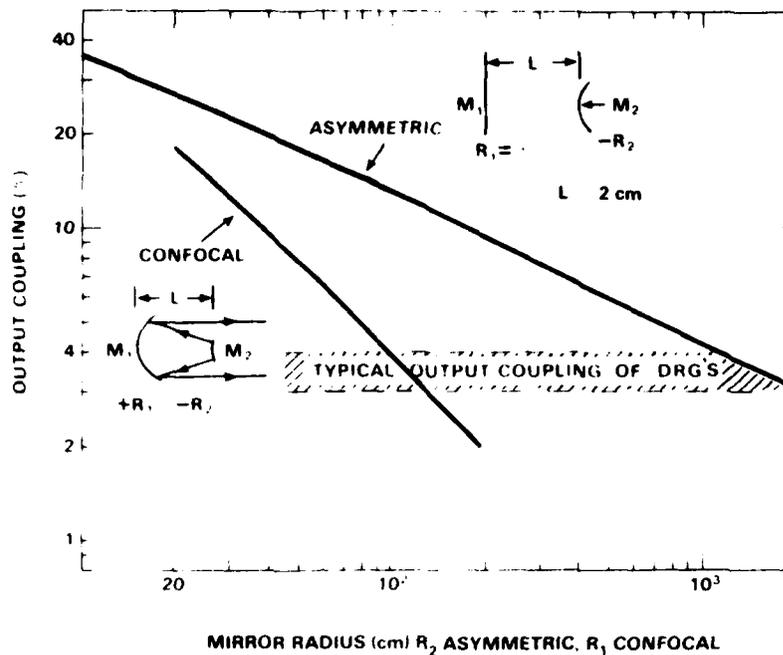
Figure 12. Variation of output coupling
of diffraction radiation generator with
cylindrical mirror radius of positive branch
asymmetric unstable resonators.

The output coupling of an asymmetric positive branch unstable reson-
ator with a flat mirror and a cylindrcal output mirror is shown in
figure 12 to be similar to that of a confocal asymmetric unstable
resonator (cylindrical mirrors) and unlike that of a negative branch
unstable resonator (shown in fig. 11). The output coupling is not
extremely sensitive to mirror radius.

For a typical DRG output coupling of 3 to 4 percent, the mirror
radii of a positive branch confocal unstable resonator with cylindrical
mirrors would be approximately 100 cm. Similarly, the radius of curva-
ture of the output mirror of the asymmetric positive branch unstable
resonator with a planar mirror (on which the diffraction grating could
be conveniently located) would be of the order of -20 m for a mirror
separation of 2 cm. The 100-cm radius is practical for a mirror; 20 m
borders on impracticality.

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The output of these positive branch unstable resonators would consist of two strips parallel to the generatrix of the cylindrical mirror surfaces. If it were found to be advantageous to use the walk-off properties of the unstable resonator to extend the cavity mode along the length of the grating (rather than across it as in fig. 9), the resonator configurations shown in figure 10 could possibly be used. In the direction across the grating, the resonator could be made to be stable, while along the grating the resonator could be unstable. The output would consist of two blobs at each end of the unstable resonator along the axis of the diffraction grating.

For completeness, characteristics of unstable resonators proposed as likely candidates for DRG's are presented in tables 1 to 4. The characteristics have as a basis parameters that have been determined to be practical for DRG's operating at wavelengths of a few millimeters[1] and less than 1 mm.[1,18]

TABLE 1. CHARACTERISTICS OF ASYMMETRIC POSITIVE BRANCH UNSTABLE RESONATOR FOR DIFFRACTION RADIATION GENERATOR TO OPERATE AT 4-mm WAVELENGTH		TABLE 2. CHARACTERISTICS OF ASYMMETRIC POSITIVE BRANCH UNSTABLE RESONATOR FOR DIFFRACTION RADIATION GENERATOR TO OPERATE AT SUBMILLIMETER WAVELENGTH	
Parameter	Value	Parameter	Value
Diffraction grating		Diffraction grating	
Length of grooves	40 mm	Length of grooves	25 mm
Width of grooves	10 mm	Width of grooves	7 mm
Depth of grooves	0.92 mm	Depth of grooves	0.19 mm
Protrusion of grating above mirror surface M_1	0.6mm	Protrusion of grating above mirror surface M_1	0.15 mm
Radius of curvature		Radius of curvature	
Lower mirror (M_1)	∞	Lower mirror (M_1)	∞
Upper mirror (M_2)	-20 m	Upper mirror (M_2)	-10 m
Mirror separation	20 mm	Mirror separation	10 mm
Width of mirrors		Width of mirrors	
M_1	40 mm	M_1	30.0 mm
M_2	39.4 mm	M_2	29.6 mm
Output coupling	3%	Output coupling	3%

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[1] *V. P. Shestopalov, Diffraction Electronics, Khar'kov (1976); translation by U.S. Joint Publications Research Service (April 1978); U.S. Army Foreign Science and Technology Center Document 923-77.*

[18] *V. G. Kurin, I. D. Revin, and B. K. Skrynnik, Dokl. Akad. Nauk Ukrainian SSR, 8 (1976), 815-819.*

TABLE 3. CHARACTERISTICS OF SYMMETRIC STABLE AND UNSTABLE RESONATORS FOR DIFFRACTION RADIATION GENERATOR TO OPERATE AT 4-mm WAVELENGTH	
Parameter	Value
Diffraction grating	
Length of grooves	40 mm
Width of grooves	10 mm
Depth of grooves	0.92 mm
Protrusion of grating above mirror surface M_1	0.6 mm
Radius of curvature	
Lower mirror (M_1)	
Along grating	∞
Across grating	+110 mm (cylindrical)
Upper mirror (M_2)	
Along grating	-10 m
Across grating	+110 mm
Mirror separation	20 mm
Size of cylindrical output mirror M_2 across grating	25 mm
Length of cylindrical out mirror M_2 along grating	39.41 mm
Output coupling	3%

TABLE 4. CHARACTERISTICS OF ASYMMETRIC STABLE AND UNSTABLE RESONATORS FOR DIFFRACTION RADIATION GENERATOR TO OPERATE AT SUBMILLIMETER WAVELENGTH	
Parameter	Value
Diffraction grating	
Length of grooves	25.0 mm
Width of grooves	7 mm
Depth of grooves	0.19 mm
Protrusion of grating above mirror surface M_1	0.15 mm
Radius of Curvature	
Lower mirror (M_1)	
Along grating	∞
Across grating	+110 mm (cylindrical)
Upper mirror (M_2)	
Along grating	-10 m
Across grating	80 mm (cylindrical)
Mirror separation	10 mm
Size of cylindrical output mirror M_2	
Along grating	24.63 mm
Across grating	25 mm
Size of lower mirror M_1	
Along grating	25.0 mm
Across grating	25 mm
Output coupling	3%

4. SUMMARY

Basic configurations of unstable resonators have been drawn for use with DRG's. Configurations are possible with diffraction losses (output coupling) of a few percent, appropriate for the optical gains realized in DRG's.

The output coupling of a negative branch unstable resonator exhibits an extreme sensitivity to mirror radius without any obvious advantages. This type of unstable resonator, therefore, appears to be unsuited to DRG's.

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The positive branch unstable resonator configuration does not exhibit any extreme sensitivity to mirror radius and appears suitable for use with DRG's. Furthermore, the radii of curvature of the mirrors needed to give output couplings of a few percent are practicable.

There is one reservation: DRG's require both high-Q cavities and high electric field strengths (E^2's) localized in the interaction region of the ribbon-like electron beam and the grating. Whereas it has been shown here that unstable resonator configurations for DRG's with high-Q cavities are possible, it is not known whether they have spatial E^2 distributions that allow for a good electron beam and diffraction grating interaction region. Their actual characteristics and suitability as resonators for DRG's, however, could presumably be determined in experiments similar to those carried out on stable DRG resonators.[1,19]

[1]V. P. Shestopalov, *Diffraction Electronics*, *Khar'kov (1976);* *translation by U.S. Joint Publications Research Service (April 1978);* *U.S. Army Foreign Science and Technology Center Document 923-77.*

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